Where is scattering important in nanotransistors?

M. P. Anantram & Alexei Svizhenko
Center for Nanotechnology
NASA Ames Research Center
Moffett Field, California

Equations

- Developed algorithms and models for 2D (quasi-1D) simulation of nanostructures

- Equations for retarded (G^r) and less-than ($G^<$) Green's functions:

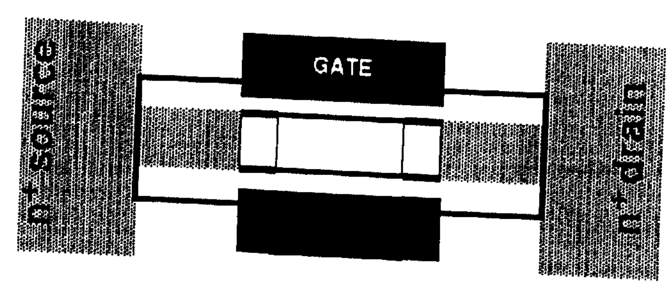
$$(E-H-\Sigma^r)\, G^r(r,r',E) = \delta(r-r')$$

$$(E-H-\Sigma^r)\, G^<(r,r',E) = \Sigma^< \, G^a(r,r',E)$$

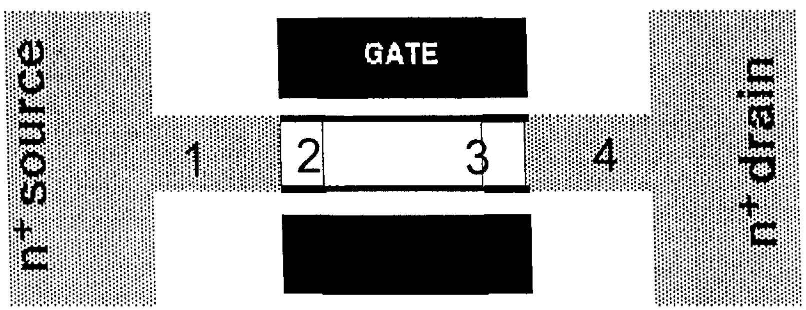
$$(E-H-\Sigma^r)\, G^>(r,r',E) = \Sigma^> \, G^a(r,r',E)$$

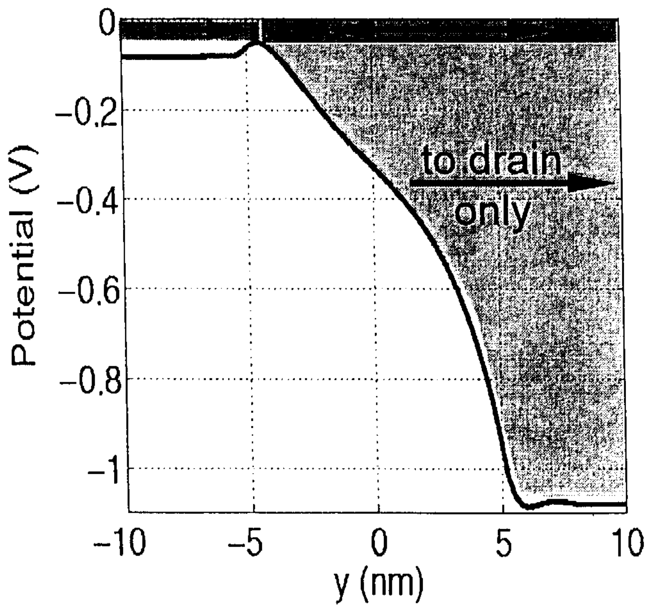
- Σ^r represents self-energy due to <u>open boundaries</u> and <u>electron-phonon</u> scattering (self-consistent Born approx.)

- Poisson's equation



Where is scattering most detrimental to on-current? Region 1, 2, 3 & 4 below?



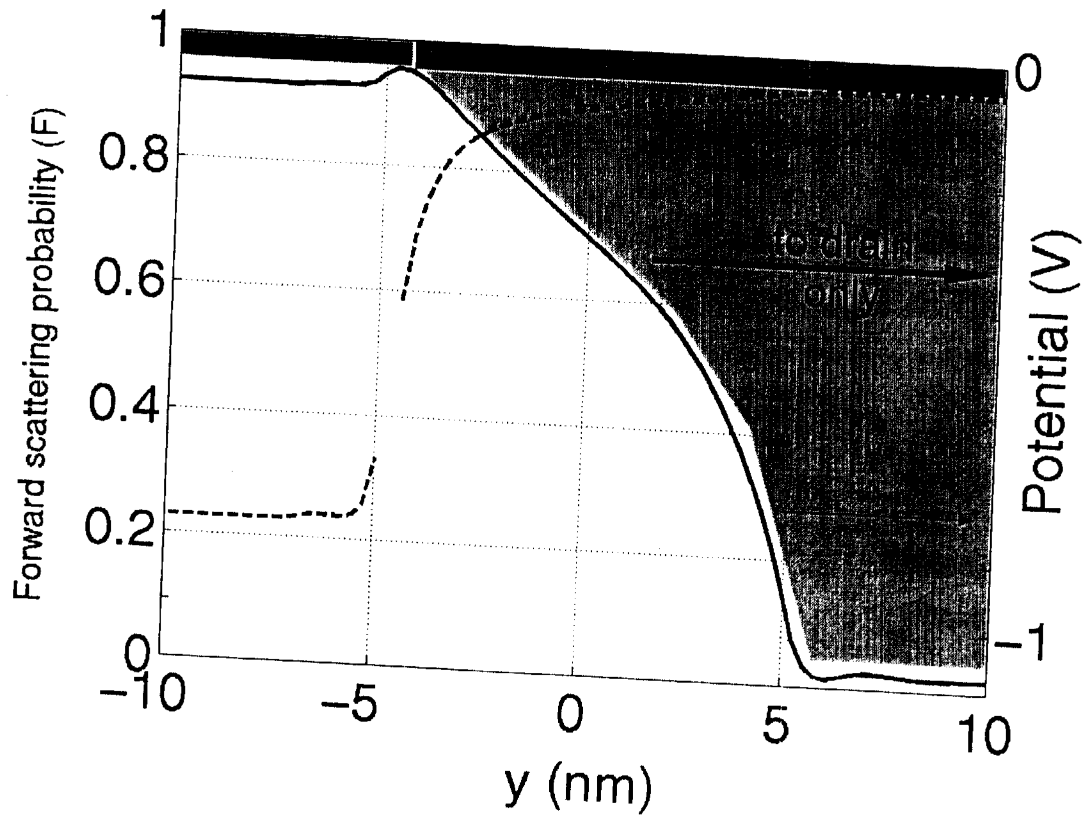


Competing Factors

1. Energy relaxation in the drain-end
2. Poisson's equation: Source injection barrier height.

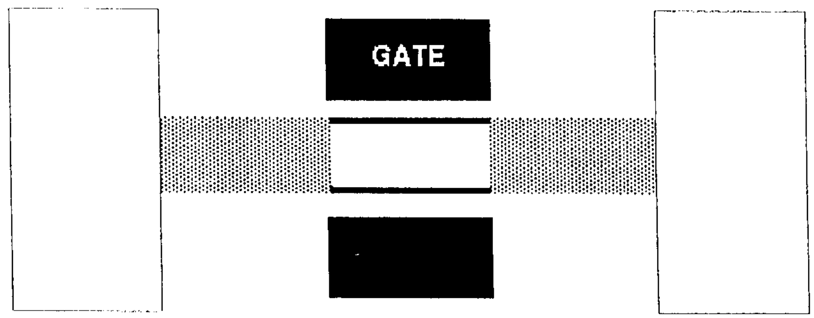
- Simple models have assumed:

  - Scattering is important only in the source-end.
  - The extension regions can be modeled as series resistances

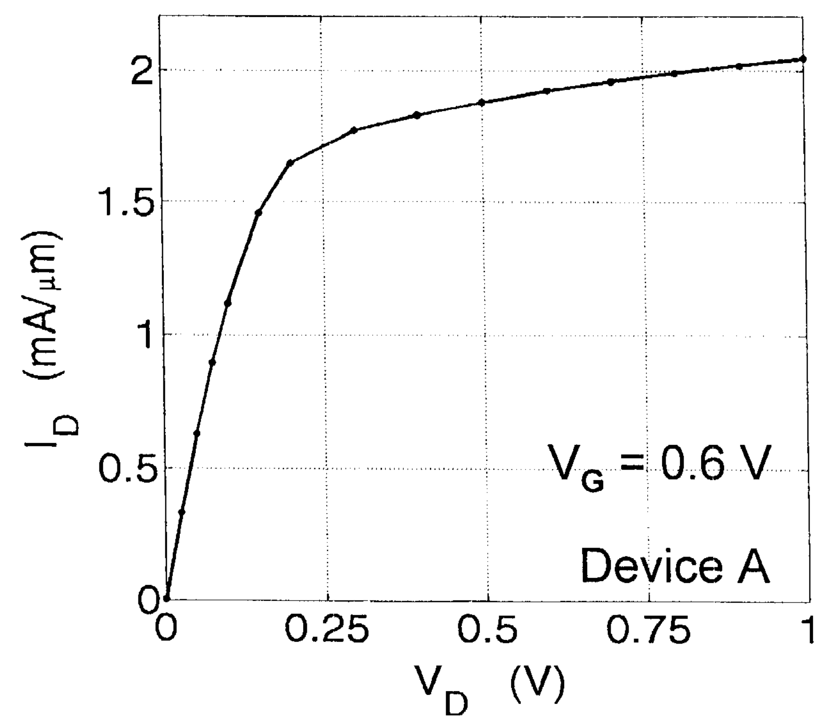


- No charge self-consistency.
- The reflected carriers contribute to channel charge. It's contribution to current is non-linear!

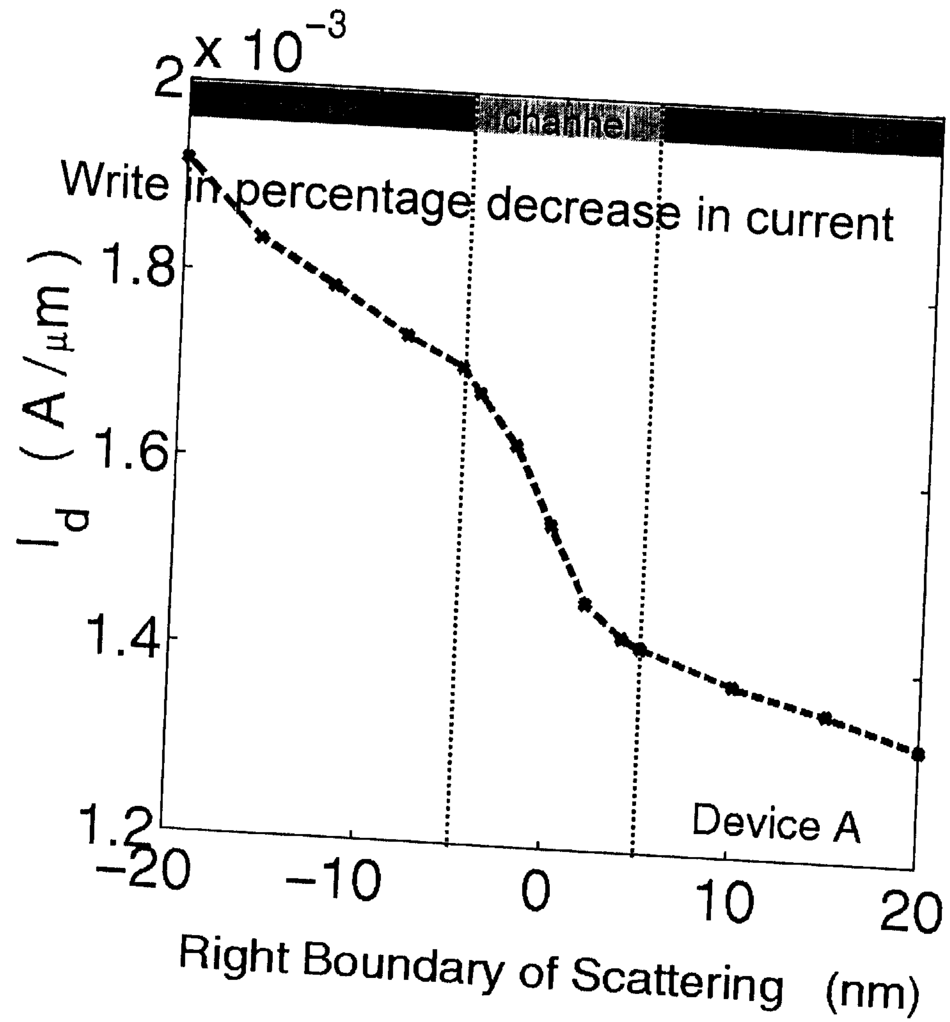
Device A: L_{ch} = 10 nm



L_{ch} = 10 nm or 25 nm
T_{ch} = 1.5nm
T_{ox}=1.5nm
Gate dielectric = 3.9 or 20
Doping = 1E+20 cm^{-3}
Channel is intrinsic



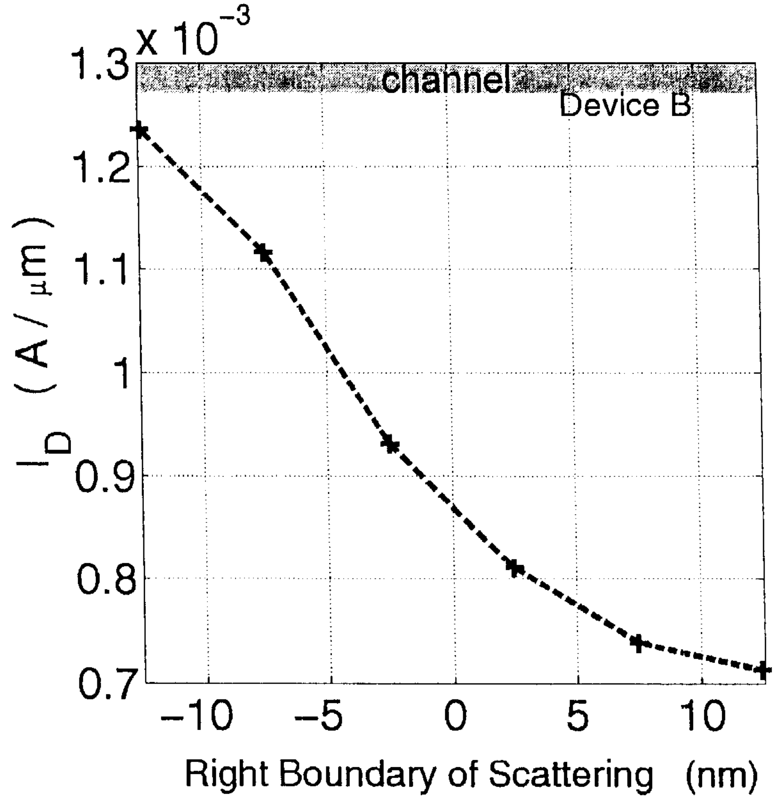
Device A: L_{ch} = 10 nm



L_{ch} = 10 nm
L_{scatt} = 10 nm

Ballisticity = 68%

Device B: L_{ch} = 25 nm

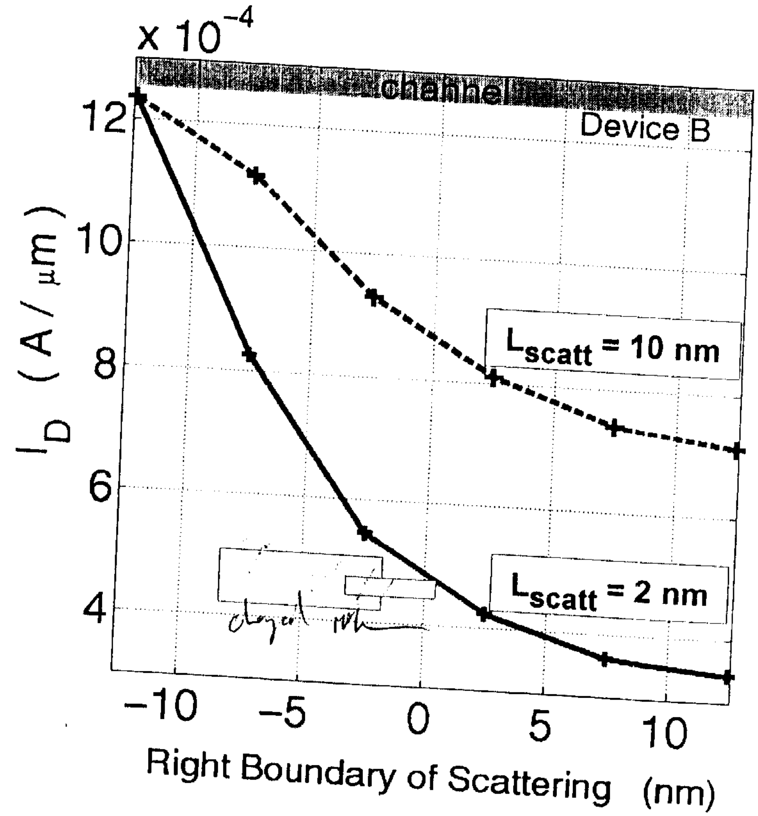


L_{ch} = 25 nm
L_{scatt} = 10 nm

Ballisticity = 57%
Left Half = 69%
Right Half = 31%

- Scattering in the right half (of channel) is comparable to scattering in the left half, in causing on-current reduction.
- What happens when the scattering length is smaller?

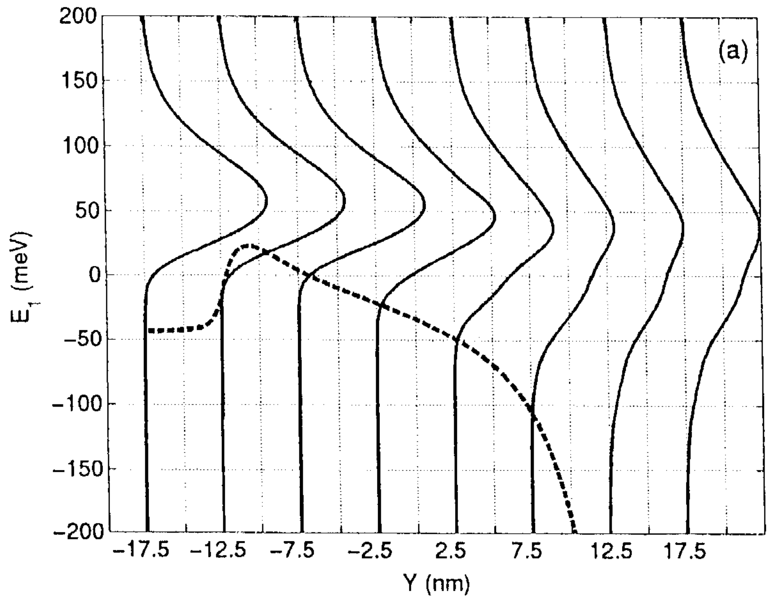
What happens when $L_{ch} >> L_{scatt}$?



L_{ch} = 25 nm

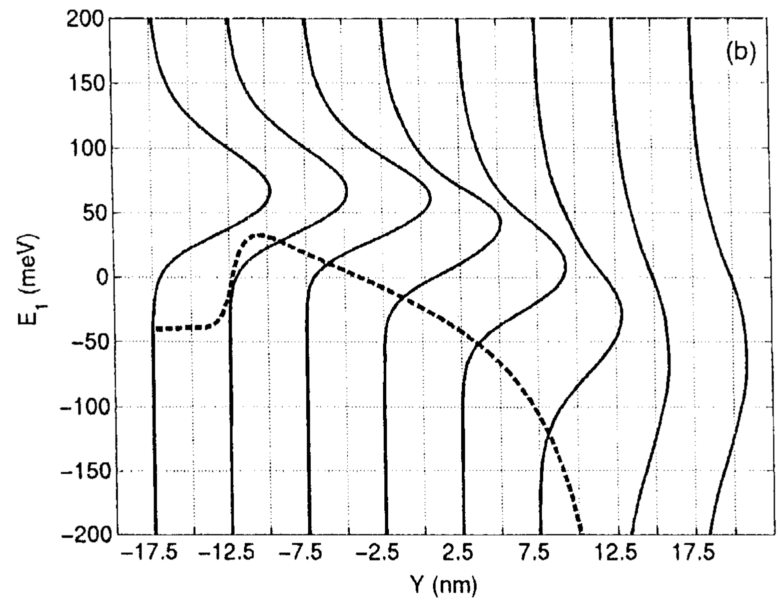
- As L_{ch} becomes much larger than L_{scatt}, scattering in the source-end becomes much more important than the drain-end

L_{scatt} = 10 nm



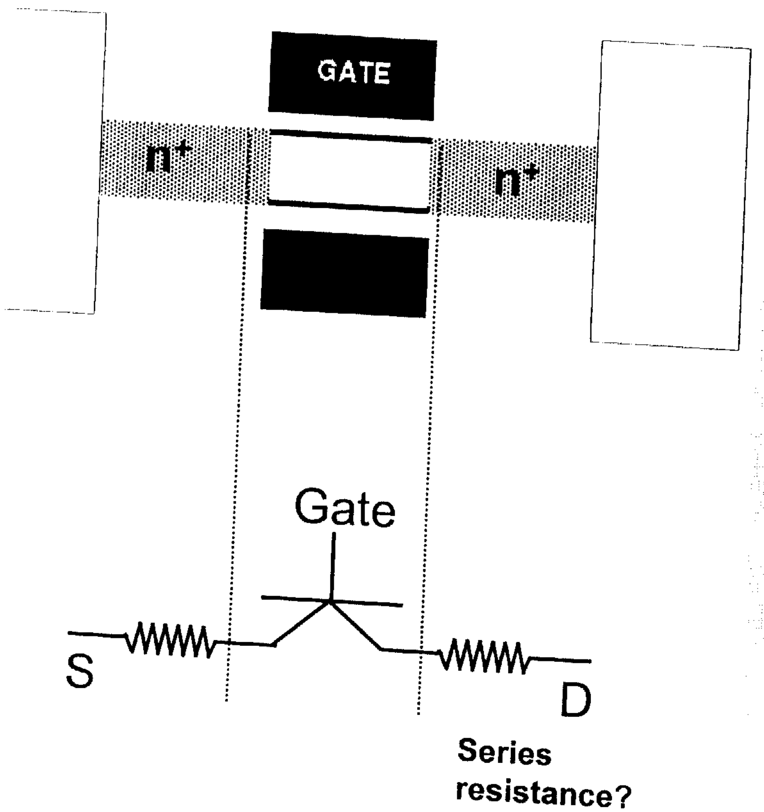
- Hot carriers at drain end
- Reflection at drain-end has a large influence

L_{scatt} = 2 nm

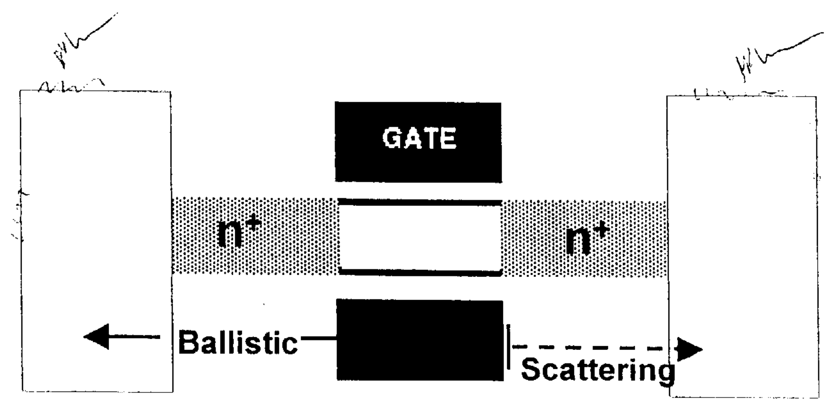


- Thermalized at drain end
- Reflection at drain-end has only a small influence

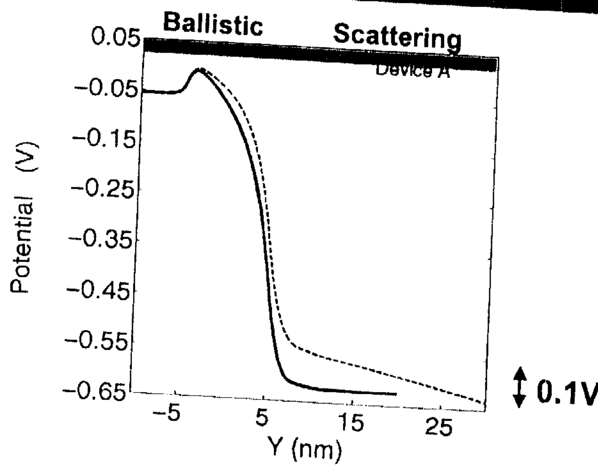
Series Resistance?

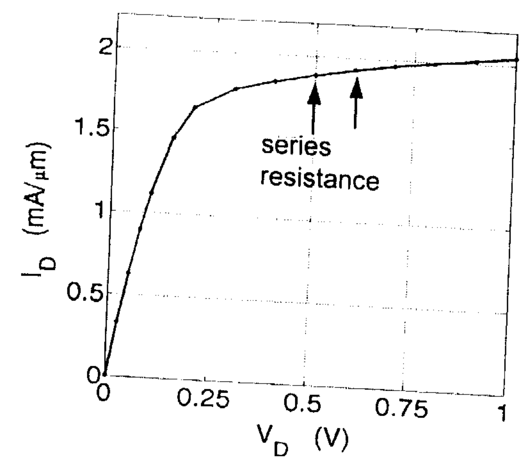


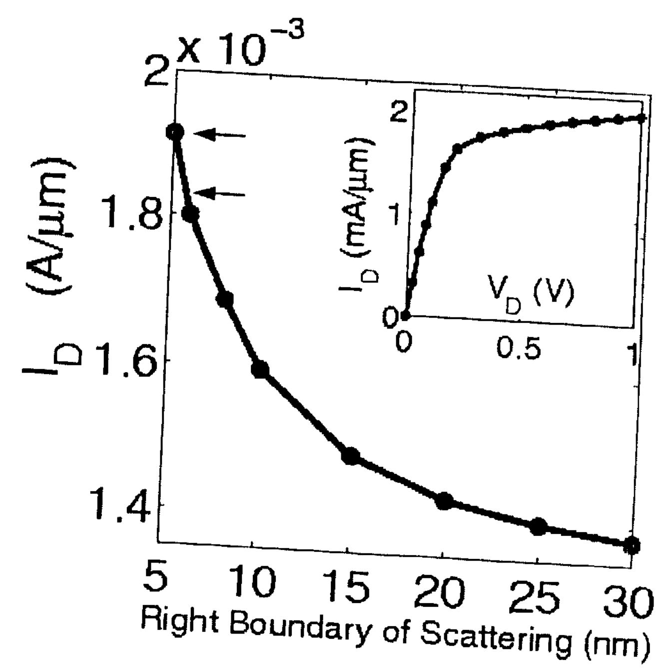
- Conventional methods treat the extension regions as a series resistance that can be added to an equivalent circuit.
- Voltage drops: $I_D R_S$ and $I_D R_D$
- $I_D[V_D, V_G] \rightarrow I_D[V_D - I_D(R_S + R_D), V_G - I_D R_S]$
- Can the highly doped extension regions be modeled as series resistances?

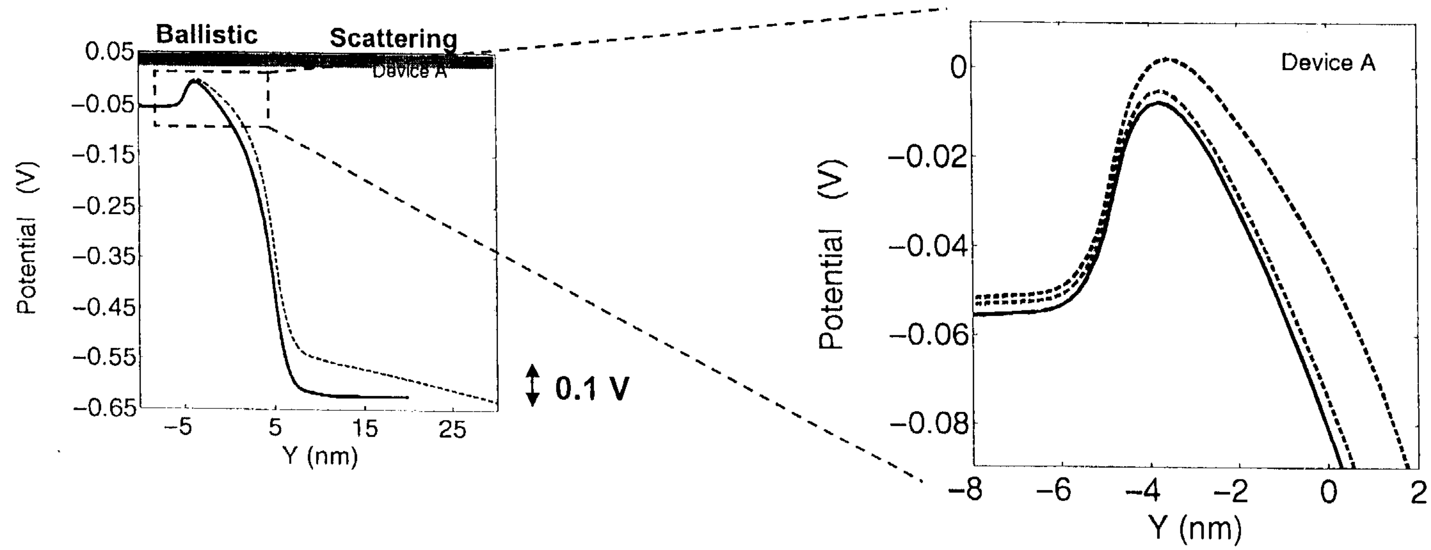

GATE
n+
n+
Ballistic
Scattering

Potential, series resistance, current









- Source injection barrier increases due to scattering in the drain
- V_D = 0.6 V - 0.1 V = 0.5 V (red line)

- If the channel is ballistic, scattering in the drain extension causes a super-linear decrease in current because of electrostatics.